

REMARKS

Claims 53-118 are pending. Claims 53-56 are amended, and claims 111 and 112 are cancelled. Reconsideration and allowance of the present application based on the following remarks are respectfully requested.

Rejection under 35 U.S.C § 112

Claims 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 114, 116 and 118 are rejected under 35 U.S.C. § 112, first paragraph. The Office Action alleges that "[t]here is no support for the range of [the] claimed limitation silane to ammonia ratio of 6×10^{-10} [SIC; 8.6×10^{-10}] to 2.6×10^{-8} ." Applicants respectfully traverse the rejection.

The claim-specified feature (recited in independent claims 54 and 56) of setting a supplying rate of silicon (Si) to NH_3 during vapor phase epitaxy at a desired value in a range from 8.6×10^{-10} to 2.6×10^{-8} finds support at page 28, lines 2-14 of the Specification.

In particular, the Specification discloses a flow rate of 10 l/min of NH_3 and a range for a flow rate of silane in an H_2 carrier gas of 10 cc/min to 300 cc/min, at a concentration of 0.86 parts silane per 1,000,000 parts H_2 . Properly accounting for the concentration of 0.86 ppm silane in the range for the flow rate of H_2 /silane, there is clear support for the claim-specified range of setting a supplying ratio of silicon to NH_3 of 8.6×10^{-10} to 2.6×10^{-8} , as recited in independent claims 54 and 56. The other enumerated claims all depend directly or indirectly from independent claims 54 and 56. Accordingly, Applicants respectfully request that the rejection be withdrawn.

The Office Action instructs that claims 111 and 112 should be cancelled, as they depend from previously canceled claims. Applicants have done so.

Rejection under 35 U.S.C § 103

Claims 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, 75, 77, 79, 81, 83, 85, 87, 89, 91, 93, 95, 97, 99, 101, 103, 105, 107, 109, 113, 115, and 117 are rejected under 35 U.S.C. § 103(a) over Khan et al., U.S. Patent No. 4,614,961 ("Khan '961") in view of Koide et al., "Epitaxial Growth and Properties of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ by MOVPE" and further in view of Sayyah, "A Study of Growth Mechanisms and Electrical and Optical Properties of Epitaxial $\text{Al}_x\text{Ga}_{1-x}\text{N}$ Layers

Grown By Atmospheric Pressure Metalorganic Chemical Vapor Deposition.” Applicants respectfully traverse the rejection.

The invention is directed to a method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy and, more particularly, for controlling conductivity or carrier concentration of the semiconductor. A gas containing silicon (e.g., silane (SiH_4)) and a gas containing other materials (e.g., gallium (Ga)) are supplied in a reaction chamber during a crystal growth process of the gallium nitride compound semiconductor. Controlling the ratio of the gas containing silicon to the gas containing the other materials controls the semiconductor conductivity or carrier concentration. For example, Fig. 26 illustrates that when the ratio of the gas containing silicon (e.g., silane (SiH_4)) is increased, the semiconductor carrier (electron) concentration increases as well. That increased carrier concentration indicates that silicon functions as a donor impurity in the present invention.

Furthermore, while the carrier concentration increases with an increase in the silane flow rate, resistivity of the semiconductor decreases with an increase in the silane flow rate. Because conductivity is inversely proportional to resistivity, the resistivity decrease shown in Fig. 26 indicates that conductivity --like the semiconductor carrier concentration-- also increases with increased silane flow rate.

Accordingly, setting the supplying rate of silicon to gallium controls the carrier concentration of the gallium nitride group compound semiconductor, such that the conductivity increases with increasing the supplying ratio, as recited in independent claim 53. Similarly, setting the supplying rate of silicon to gallium controls the carrier concentration of the gallium nitride group compound semiconductor, such that the carrier concentration increases with increasing the supplying ratio, as recited in independent claim 55.

Overlooking this fundamental aspect of the claimed invention, the Office Action acknowledges that “Khan et al. does not [disclose] examples [of] n-type dopants.” The Office Action then alleges, however, that “silicon is the most common and preferred element in the gallium nitride compound semiconductor materials” such that allegedly it would have been obvious for one of ordinary skill in the art to combine the use of silicon as an n-type dopant with the teaching of Khan et al. Applicants firmly refute this assertion. At the time of invention, one of ordinary skill in the art would not have preferred silicon as an n-type dopant.

For example, Khan et al., "EFFECT OF Si ON PHOTOLUMINESCENCE OF GaN," ("the Khan article," cited in the information disclosure statement filed May 20, 2002) discloses that "it may be argued that Si behaves as an acceptor of this D-A pair band" (page 409, lines 5-6, emphasis added). In other words, the Khan article teaches that silicon is not a donor impurity (i.e., not n-type), but rather, an acceptor impurity (i.e., p-type). Thus, the Khan article supports Applicants' assertion that one of skill in the art at the time of the invention would not have preferred silicon as an n-type dopant, as the Office Action alleges.

Furthermore, the Khan article "agree[s] with the concepts of Pankove et al. that the donors are believed to be nitrogen vacancies" (page 409, lines 7-9). In other words, the Khan article teaches that the donor impurity (i.e. n-type dopant) in a semiconductor comprising nitrogen atoms (e.g., a gallium nitride compound semiconductor) is a nitrogen vacancy, not silicon.

Additionally, Applicants submit that at the time of invention, one of skill in the art would have been led to believe that doping a gallium nitride compound semiconductor with silicon would not increase the electron concentration (i.e., carrier concentration or conductivity).

For example, Pankove et al., "OPTICAL ABSORPTION [SIC] OF GaN", (cited in the information disclosure statement filed October 2, 2000) discloses that "undoped GaN is n-type with an electron concentration of at least 10^{19} cm^{-3} " (page 197, bottom of the right column, lines 2-4). Because the undoped GaN disclosed in Pankove et al. has an electron concentration of at least 10^{19} cm^{-3} , the addition of a dopant will be indicated by a change in the electron concentration. For example, the addition of an n-type dopant (i.e. carrier donor) would increase the carrier concentration, while the addition of a p-type dopant (i.e. carrier acceptor) would decrease the electron concentration. On page 198, in the description of Fig. 1 at the top of the left column, Pankove et al. discloses GaN that has been doped with silicon and that has an electron concentration $3 \times 10^{18} \text{ electrons/cm}^3$. The electron concentration (i.e., carrier concentration) of the silicon-doped GaN ($3 \times 10^{18} \text{ electrons/cm}^3$) is lower than the non-doped GaN electron concentration ($10^{19} \text{ cm}^{-3} \text{ electrons/cm}^3$). Accordingly, in view of the reduction of the carrier concentration in the silicon-doped GaN, it is apparent that silicon behaves as an acceptor impurity in Pankove et al. because the addition of silicon has reduced the carrier concentration. Thus, it may be inferred from Pankove et al. that one of skill in the art at the time of the invention would not have preferred silicon as a donor (i.e., n-type) impurity to increase the carrier concentration.

Still further, Sayyah "A Study of Growth Mechanisms and Electrical and Optical Properties of Epitaxial $\text{Al}_x\text{Ga}_{1-x}\text{N}$ Layers Grown By Atmospheric Pressure Metalorganic Chemical Vapor Deposition," (cited in the information disclosure statement filed October 2, 2000) discloses that "[t]he silicon doping of... $\text{Al}_x\text{Ga}_{1-x}\text{N}$ samples did not change... the films from semi-insulating to conducting [and that] $\text{Al}_x\text{Ga}_{1-x}\text{N}$ samples... were doped with Si... without observation of any measurable conductivity." (Page 135, lines 18-22). In other words, Sayyah teaches that even when $\text{Al}_x\text{Ga}_{1-x}\text{N}$ having comparatively high mol fraction of aluminum is doped with silicon to a doping concentration of $8 \times 10^{21}/\text{cm}^3$, the conductivity of the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ does not change. Thus, in view of that teaching, one of ordinary skill in the art would not have been motivated to use silicon as a dopant to control conductivity of a semiconductor.

Accordingly, Applicants submit that it would not have been obvious to one of skill in the art to utilize silicon as an n-type dopant to increase carrier concentration or conductivity, particularly in view of the state of the art as demonstrated by Khan '961, the Khan article, and Sayyah.

Thus, Applicants submit that Khan et al. fails to disclose or suggest setting a supplying rate of silicon to gallium at a desired value in a range to control conductivity at a desired value such that the conductivity increases with increasing the supplying ratio, as recited in independent claim 53. Similarly, Applicants submit that Khan et al. fails to disclose or suggest setting a supplying rate of silicon to gallium at a desired value in a range to control carrier concentration at a desired value such that the carrier concentration increases with increasing the supplying ratio, as recited in independent claim 55.

With respect to Koide et al., that reference is directed to growing epitaxial layers of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ alloys to reduce parasitic reactions and does not disclose setting a supplying rate of silicon to gallium at a desired value in a range to control conductivity or carrier concentration such that the conductivity or carrier concentration increases with increasing the supplying ratio. Accordingly, Koide et al. fails to remedy the deficiencies set forth above with respect to Khan et al.

The Office Action further alleges that Sayyah discloses a ratio of silane to TMG of 10^{-2} to 10^{-1} , and that it would have been obvious to one of ordinary skill to use the ratio of silane to TMG as suggested by Sayyah because such a range is suitable for growing GaN layers. Applicants respectfully disagree.

Sayyah illustrates in Fig. 27 that the $\text{SiH}_4 / (\text{TMG} + \text{TMA})$ ratio is in a range of 0 to 0.1. This ratio, however, does not control conductivity or electron concentration. Rather, Sayyah only teaches that an uptake quantity of Ga and Al varies according to a doping quantity of Si. Because Sayyah only teaches that the uptake quantity of Ga and Al varies, and not the conductivity or electron concentration, Sayyah does not suggest controlling setting a supplying rate of silicon to gallium at a desired value in a range to control conductivity or carrier concentration such that the conductivity or carrier concentration increases with increasing the supplying ratio in view of Sayyah. This is particularly so in view of the comments above with respect to Sayyah's teaching that doping $\text{Al}_x\text{Ga}_{1-x}\text{N}$ with silicon did not change the conductivity of $\text{Al}_x\text{Ga}_{1-x}\text{N}$.

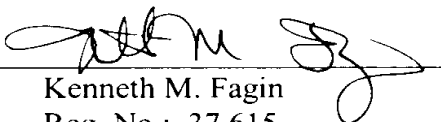
Thus, Applicants submit that independent claims 53-56 are allowable. The other claims not addressed specifically all depend directly or indirectly from independent claims 53 or 55. Applicants respectfully submit that the claims are allowable, and request that the rejection be withdrawn.

In view of the foregoing, the claims are now believed to be in form for allowance, and such action is hereby solicited. If any point remains in issue which the Examiner feels may be best resolved through a personal or telephone interview, please contact the undersigned at the telephone number listed below.

Attached is a marked-up version of the changes made to the claims by the current amendment. The attached Appendix is captioned **"Version with markings to show changes made"**.

All objections and rejections having been addressed, it is respectfully submitted that the present application is in a condition for allowance and a Notice to that effect is earnestly solicited.

Respectfully submitted,
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Enclosure: Appendix

APPENDIX

VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE CLAIMS:

Claims 111 and 112 have been cancelled.

Claims 53-56 have been amended as follows:

53. (Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising the steps of:
setting a supplying rate of silicon (Si) to gallium (Ga) in a reaction chamber during said vapor phase epitaxy at a desired value in a range from 0.1 to 3 as [a] converted values so as to control [a] conductivity (1/resistivity) of said gallium nitride group compound semiconductor at a desired value such that said conductivity increases with increasing of said supplying ratio, where said values 0.1 and 3 are the values obtained from gas flow rates, in case that an amount of said gallium (Ga) is converted into a flow rate of hydrogen bubbling trimethyl gallium (TMG) at a temperature of -15°C and an amount of said silicon (Si) is converted into a flow rate of a gas diluted to 0.86 ppm.

54. (Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising the steps of:
setting a supplying rate of silicon (Si) to NH₃ in a reaction chamber during said vapor phase epitaxy at a desired value in a range from 8.6×10^{-10} to 2.6×10^{-8} , so as to control [a] conductivity (1/resistivity) of said gallium nitride group compound semiconductor at a desired value such that said conductivity increases with increasing of said supplying ratio.

55. (Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising the steps of:
setting a supplying rate of silicon (Si) to gallium (Ga) in a reaction chamber during said vapor phase epitaxy at a desired value in a range from 0.1 to 3 as [a] converted values so as to control a carrier concentration of said gallium nitride group compound semiconductor at a desired value such that said carrier concentration increases with increasing of said supplying ratio, where said values 0.1 and 3 are the values obtained from gas flow rates, in case that an amount of said gallium (Ga) is converted into a flow rate of hydrogen bubbling trimethyl

gallium (TMG) at a temperature of -15°C and an amount of said silicon (Si) is converted into a flow rate of a gas diluted to 0.86 ppm.

56. (Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising the steps of:
setting a supplying rate of silicon (Si) to NH_3 in a reaction chamber during said vapor phase epitaxy at a desired value in a range from 8.6×10^{-10} to 2.6×10^{-8} , so as to control a carrier concentration of said gallium nitride group compound semiconductor at a desired value such that said carrier concentration increases with increasing of said supplying ratio.

End of Appendix